SHEAR STRENGTH OF SIMPLY-SUPPORTED PRESTRESSED CONCRETE BEAMS

BY

EUGENE MILTON ZWOYER

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M.S., Illinois Institute of Technology, 1949

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IN THE GRADUATE COLLEGE OF THE
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This thesis is based on the results of an investigation concerned with prestressed concrete, sponsored jointly by the Division of Highways of The State of Illinois and The Bureau of Public Roads, U. S. Department of Commerce, and conducted in the Engineering Experiment Station of the University of Illinois. The privilege of using the results of the investigation in this thesis is appreciated.

The writer is indebted to his advisor, Dr. N. M. Newmark, Professor of Structural Engineering at the University of Illinois, for suggestions and encouragement throughout the work on this thesis and for general direction of the investigation of which this thesis is a part.

Dr. C. P. Siess, Research Associate Professor of Civil Engineering at the University of Illinois, provided supervision for the investigation and his helpful suggestions and guidance are deeply appreciated.

SHEAR STRENGTH OF SIMPLY-SUPPORTED PRESTRESSED CONCRETE BEAMS

Although prestressed concrete may be economical and its use involves a savings in material, many American engineers have been reluctant to use it because of a lack of knowledge of its behavior under load. What we know about the behavior and load-carrying capacity of concrete structures has been derived primarily from tests on individual members. Only a few scattered tests on prestressed concrete members and to the writer's knowledge no tests on entire structures have been reported to date. As yet, not even a set of specifications governing design of prestressed concrete structures has been adopted for general use in this country, not is it likely that any will be adopted until a knowledge is gained of modes of failure, ultimate strengths, and general behavior under load of structural members.

In order to increase our knowledge of prestressed concrete, a research project was initiated in July, 1951. One phase of this investigation is concerned with the ultimate strength and the behavior under load of prestressed concrete beams which fail in shear and is the basis for this thesis.

The theoretical studies and the tests carried out in connection with this investigation were planned with the following objectives:

1. To determine the modes and characteristics of shear failures in simply-supported prestressed concrete beams without web reinforcement.

2. To determine the effect of the following variables on the ultimate shear strength:
   a. concrete strength
   b. amount of longitudinal steel
   c. ratio of shear span to depth of beam
   d. prestress in the steel
   e. size of grout core in post-tensioned beams

3. To determine the difference, if any, between the modes of failure for rectangular beams and I-beams.

4. To establish a basis for future tests involving additional variables.

A total of 38 beams was tested. Thirty-four of the beams were rectangular in cross section with dimensions 6 in. by 12 in. by 10 ft.-0 in. long and four of the beams had an I cross section with the same overall dimensions. The I-beams and two of the rectangular beams were pre-tensioned and all others were post-tensioned, end-anchored and grouted. The I-beams and 23 of the rectangular beams were loaded at the third points on a 9-ft. span; seven of the rectangular beams were loaded at the center point on a 9-ft. span; and four of the rectangular beams were loaded with two equal loads each placed 2 ft. from the supports on a 7-ft. span.

The tests are described, and the test results are presented in both tabular and graphical form in the thesis.

A rational analysis has been developed for computing the ultimate strength of prestressed concrete simply-supported beams failing in shear. It is based on the fact that the mode of failure is crushing of the concrete over diagonal tension cracks. It makes use of an empirical method of calculating the depth to the neutral axis at ultimate load. The form of the equations is valid for beams with or without web reinforcement and for beams with or without prestress.

An extensive program of additional tests have been recommended which was planned to include new variables such as changes in cross section, web reinforcement, end-restraint, and distributed rather than concentrated loading.

The following conclusions are based on the results of the investigation:

1. The presence of shear in a simple beam of prestressed concrete has the effect of causing diagonal tension cracks. For beams with low ratios of percentage of steel to concrete

strength, the pure flexure cracks will develop faster than the diagonal tension cracks, initial failure will be by yielding of the steel, and final failure by crushing of the concrete above the pure flexure cracks. For beams with higher values of the ratio, the diagonal tension cracks develop faster than the pure flexure cracks, and final failure will occur by crushing of the concrete above the diagonal tension cracks before the steel yields. This mode of failure is called a shear failure; it occurs at a load lower than the flexural capacity of the beam. An initial compression failure does not occur in beams without web reinforcement.

2. The beams were found to fail at some limiting moment and not at some limiting shear. The grout core in the post-tensioned beams appeared to have no effect on the ultimate strength of the beams in spite of its rather large size.

3. It appears that I-beams will fail at lower loads than rectangular beams because their lower moment of inertia and thin webs reduce the cracking loads and increase the subsequent deformations in the beam. Given a rectangular beam and an I-beam with otherwise identical properties, the deformations and strains will be greater in the I-beam than in the rectangular beam for any given load. Since failure occurs by crushing of the concrete at some limiting strain, the I-beam will fail at a lower load.

4. Since the beams failed by crushing of the concrete while the steel stresses were still in the elastic range, a formula similar to that for flexural compression failures was used to compute the ultimate load. The failures differed from compression failures in that crushing occurred over diagonal tension cracks rather than pure flexure cracks. The ultimate load formula for these shear failures differs from that for flexural compression failures in that the depth to the neutral axis (or depth of the compression zone) at ultimate load is expressed empirically.

5. The depth to the neutral axis at ultimate load and thus the ultimate load was found to increase with the effective

prestress in the steel as well as with the percentage of longitudinal steel and the concrete strength. A study of ordinary reinforced concrete beams with web reinforcement indicated that the depth to the neutral axis increases linearly with the percentage of web reinforcement.

6. A study of ordinary reinforced concrete simple beams indicated that the ultimate shear strength can be expressed by the same type of formula as was developed for the prestressed concrete beams.

VITA

Eugene Milton Zwoyer was born on September 8, 1926, in Plainfield, New Jersey. He moved to Illinois in 1930. After graduating from Yorkville, Illinois, High School in 1943, he enlisted in the Navy of the United States and served in the American Theater.

Coincident with his Navy duty he attended the University of Notre Dame for two semesters, Missouri Valley College for one semester, and the University of New Mexico for four semesters. He was released from active duty in the Navy in 1946.

He then re-entered the University of New Mexico and received the degree of Bachelor of Science in Civil Engineering in June, 1947. He worked the summer of 1947 as an Assistant Engineer for the City of Aurora, Illinois.

He entered the Graduate College of the Illinois Institute of Technology in September, 1947, and was a Graduate Assistant there until August, 1948; he received the degree of Master of Science in Civil Engineering in June, 1949.

He was an Instructor of Civil Engineering at the University of New Mexico from September, 1948, to June, 1951, and an Assistant Professor (on leave) from June, 1951, to present. During the summer of 1949 he worked in the Bridge Division of the New Mexico State Highway Department, and in the summer of 1950 he worked in the Engineering Department of Eidal Manufacturing Co., Steel Fabricators in Albuquerque, New Mexico. He did structural design work for various architectural firms in Albuquerque, New Mexico during the period he was an Instructor at the University of New Mexico.

He entered the Graduate College of the University of Illinois in June, 1951. He held a one-half time Research Assistantship from June, 1951, to June, 1952, and continued as a one-half time Research Associate from June, 1952, to June, 1953.

He is a Registered Professional Engineer in the State of New Mexico.